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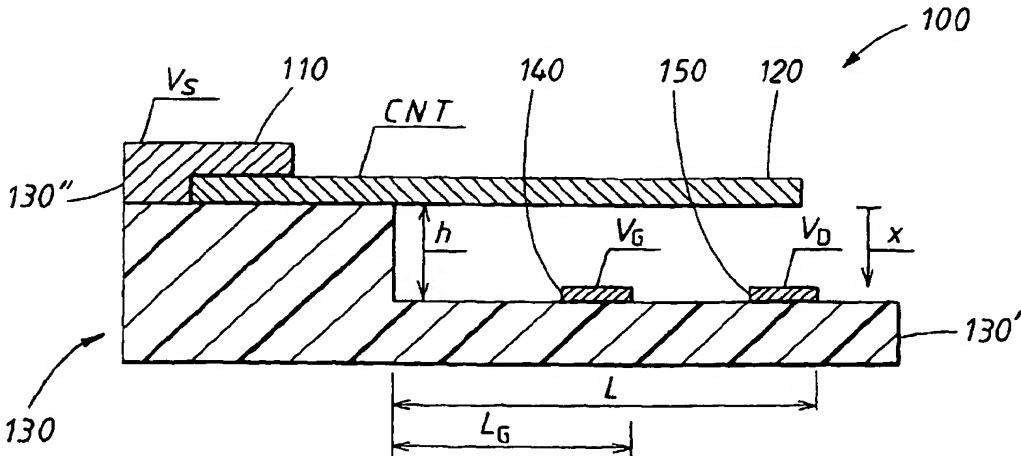
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(54) Title: NANOTUBE RELAY DEVICE



**WO 03/078305 A1**

(57) Abstract: The present invention relates to a nanotube device (100,600), comprising a nanotube with a longitudinal and a lateral extension, a structure for supporting at least first part of the nanotube, and first means for exerting a force upon the nanotube in a first direction defined by its lateral extension. At least second part of the nanotube protrudes beyond the support of said structure, so that when said force exceeds a certain level, the second part of the nanotube will flex in the direction of its lateral extension, and thereby close a first electrical circuit. Suitably, the first means for exerting said force upon the nanotube is an electrical means, the force being created by applying a voltage to the means.

**Nanotube relay device****TECHNICAL BACKGROUND**

- 5 Nanotechnology is a rapidly growing field of technology, including the development of so called nanotubes. Due to the inherently small size of the devices involved in this field of technology, nanotechnology would be ideal for applications within for example the field of electronics, for example within the semiconductor field. Memory devices are one example of an application  
10 which would benefit greatly from nanotechnology.

**SUMMARY OF THE INVENTION**

There is thus a need for a device in the nanoscale size which could serve as a multi-state logical switch or a memory element.

- 15 This need is met by the present invention in that it provides a nanotube device comprising a nanotube with a longitudinal and a lateral extension, a structure for supporting at least a first part of the nanotube, and first means for exerting a force upon the nanotube in a first direction defined by its lateral  
20 extension. At least a second part of the nanotube protrudes beyond the support of said structure, so that when said force exceeds a certain level, the second part of the nanotube will flex in the direction of its lateral extension, and thereby close a first electrical circuit.

- 25 Suitably, the first means for exerting said force upon the nanotube is an electrical means, the force being created by applying a voltage to the means.

**BRIEF DESCRIPTION OF THE DRAWINGS**

- The invention will be described in more detail below, with reference to the  
30 appended drawings, in which:

Fig 1 shows a schematic side view through a device according to the invention, and

Fig 2 shows a circuit equivalent to the device of fig 1, and

Fig 3 shows current as a function of voltages in the device of fig 1, and

- 5 Fig 4 shows an on-off transition for the current in the device in fig 1, and
- Fig 5 shows a top view of an alternative embodiment of the invention.

## EMBODIMENTS

Fig 1 shows a first embodiment of a device 100 according to the invention.

- 10 The device comprises a nanotube 120, preferably a conducting nanotube, suitably a carbon nanotube.

The device further includes a structure 130, made of a non-conducting material such as for example silicon, Si, which supports at least a first portion  
15 of the nanotube, with another second portion of the nanotube protruding beyond the supporting structure, and thus being unsupported. The first, supported, portion of the nanotube is connected to an electrode 110, referred to from now on as the source electrode.

- 20 The supporting structure 130 is suitably shaped as a terrace, and thus has a "step-like" structure, with an upper level 130'', and a lower level 130', where the two levels are interconnected by a wall-like shape of the structure 110. The difference in height between the two levels 130', 130'' of the structure as defined by the height of the wall is referred to by the letter  $h$ . It should be  
25 noted that the use of the word "level" throughout this description refers to a difference in dimensions which gives the structure a preferably step-like form either in the horizontal or in the vertical orientation of the device.

- 30 On the lower level 130' of the structure, there are arranged two additional electrodes, one being referred to as the gate electrode 140, and the other as the drain electrode, 150. The gate electrode is located at a distance  $L_G$  to

the nearest point of the wall, and the corresponding distance for the drain electrode is denoted as  $L_D$ , where  $L_G$  suitably is smaller than  $L_D$ .

The total extension of the protruding part of the nanotube is preferably within  
 5 the interval of 50 to 150 nm, suitably of the order of approximately 100 nm,  
 with the height  $h$  being approximately in the order of size of 3 nm.

When a voltage is applied to the gate electrode 140, a resulting capacitive force will act on the nanotube 120, in the direction towards the gate  
 10 electrode, which is thus a direction defined by the lateral extension of the nanotube, in the picture perceived as a "downwards" direction. The force, denoted as  $F_C$ , may be described by the mathematical formula seen below:

$$F_C = - (Q_G^2 / 2) \frac{d}{dx} (1 / C_G(x)) - (Q_D^2 / 2) \frac{d}{dx} (1 / C_D(x))$$

- 15 In this formula,  $Q_G + Q_D$  is the excess charge on the nanotube,  $C_G$  and  $C_D$  are capacitances which will be explained in more detail below with reference to fig 2, and  $x$  is the shortest distance between the nanotube 120 and the lower level 130' of the structure.
- 20 Fig 2 is an equivalent circuit 200 of the device in fig 1: The source voltage  $V_S$  is connected, via an impedance  $Z$ , to the gate voltage  $V_G$  through the capacitance  $C_G$ , and to the drain voltage  $V_D$  through the capacitance  $C_D$  and a resistance  $R_T$ , which is connected in parallel to the drain capacitance  $C_D$ . Due to the mechanical movement caused by the force  $F_C$ , the capacitances  
 25  $C_G$  and  $C_D$  and the resistance  $R_T$  will vary in time.

The resistance  $R_T$  can be expressed by the formula seen below:

$$R_T = R_0 e^{((h-x)/\lambda)}$$

$R_0$  is estimated from experimental results, and can be said to be of the order of tens to hundreds of kilohms, and the tunneling length,  $\lambda$ , is typically in the order of 0.5 Å. The distance  $x$  can, as will be realized, be varied by varying the voltage  $V_G$  applied to the gate.

5

Fig 3 shows the current-voltage function for a typical set of parameters. On one of the horizontal axes, the gate voltage,  $V_G$  is shown, and on the other horizontal axis the drain voltage,  $V_D$ , can be seen, with the vertical axis depicting the current which passes through the source electrode to the drain 10 electrode. As can be seen from this figure, there is a sharp transition from a non-conducting (off) state for the device to a conducting (on) state when the gate voltage is varied, with the source voltage fixed.

Fig 4 shows the current-voltage characteristics of the device with the source 15 voltage at a fixed value. The shift in gate voltage required to make a transition from the "off" to the "on" state is approximately 1.5 mV.

The time required to make a transition from the "on" -state to the "off"-state for the device in fig 1 is considerably much shorter than the time to make the 20 opposite transition, i.e. from the "off" -state to the "on"-state. Naturally, the switching dynamics of the device according to the invention can be affected by altering the geometry of the device, e.g. the wall height  $h$ , the positioning  $L_G$ ,  $L_D$  of the electrodes on the lower level 130' of the terrace, and the length of the protruding part  $L$  of the nanotube. Thus, by suitable design, the device 25 according to the present invention can be applied to meet the demands of different applications.

Fig 5 shows a top view of another embodiment 500 of the invention. This embodiment 500 comprises a nanotube device similar to that shown in fig 1 30 and described above, but with the supporting terraced structure 530 additionally comprising a structure 530" on a third level, said third level 530"

being located essentially in parallel with the second level 530', but on an opposite side of the protruding part of the nanotube 520.

The embodiment 500 comprises essentially all of the features of the device in  
5 fig 1, and additionally comprises second means 540' for exerting a force upon the nanotube 520 in a second direction defined by its lateral extension, so that when said force exceeds a certain level, the second part of the nanotube will flex in the second direction of its lateral extension, and thereby close a second electrical circuit. Said second direction is, as will be realized  
10 from fig 5, the direction which is towards the means 540'. When force is exerted upon the nanotube 520 via the means 540', which is preferably a second gate electrode, the second, protruding, part of the nanotube 520 will flex in the second direction of its lateral extension, and thereby close a second electrical circuit. This second electrical circuit is suitably defined by  
15 the source electrode 510 described in connection with fig 1, and a second drain electrode 550' located on the third level 530" of the supporting structure 530.

The second gate and drain electrodes are located at distances  $L_{G2}$  and  $L_{D2}$   
20 respectively from the wall of the terraced structure.

Although the invention has been described with reference to examples of certain embodiments, the invention may be varied within the scope of the appended claims.

## CLAIMS

1. A nanotube device (100,600), comprising a nanotube with a longitudinal and a lateral extension, a structure for supporting at least a first part of the  
5 nanotube, and first means for exerting a force upon the nanotube in a first direction defined by its lateral extension, characterized in that at least a second part of the nanotube protrudes beyond the support of said structure, so that when said force exceeds a certain level, the second part of the nanotube will flex in the direction of its lateral extension, and thereby close a  
10 first electrical circuit.
2. A nanotube device according to claim 1, characterized in that the first means for exerting said force upon the nanotube is an electrical means, the force being created by applying a voltage to the means.  
15
3. A nanotube device according to claims 1 or 2, in which said supporting structure comprises a terraced structure with structures on a first and a second level, with the supported first part of the nanotube being supported by the first level of the structure, and said means for exerting force being located  
20 on said second level.
4. A nanotube device according to any of claims 1-3, in which the first means for applying force comprises a first gate electrode, and the first circuit which is closed by the flexing of the nanotube comprises a first gate electrode being located on said second level of the structure and a first source electrode being located on said first level of the structure.  
25
5. A nanotube device according to any of the previous claims, in which the supporting terraced structure additionally comprises a structure on a third level, said third level being located essentially in parallel with said second level but on an opposite side of the protruding part of the nanotube, which nanotube device comprises second means for exerting a force upon the  
30

nanotube in a second direction defined by its lateral extension, so that when said force exceeds a certain level, the second part of the nanotube will flex in the second direction of its lateral extension, and thereby close a second electrical circuit.

5

6. A nanotube device according to claim 5, characterized in that the second means for exerting said force upon the nanotube is an electrical means, the force being created by applying a voltage to the means.

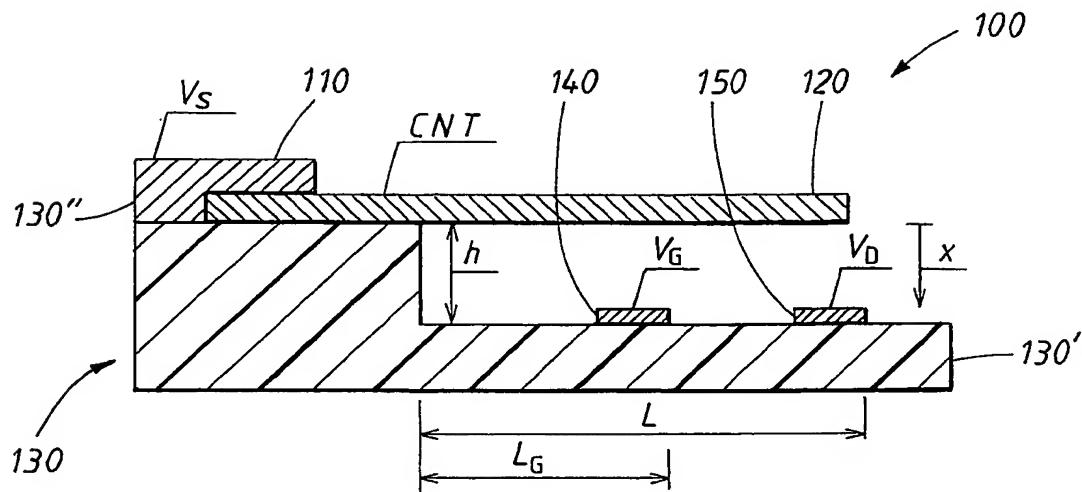
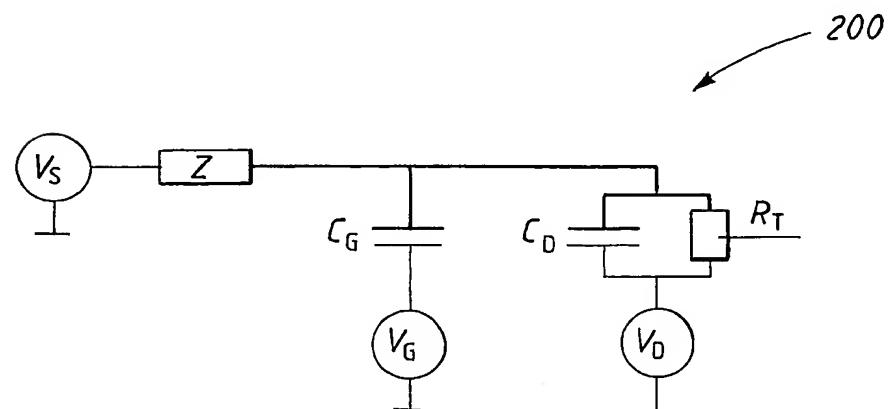
10 7. A nanotube device according to claims 5 or 6, in which said additional supporting structure comprises a terraced structure with structures on a first and a second level, with the supported first part of the nanotube being supported by the first level of the structure, and said means for exerting force being located on said second level.

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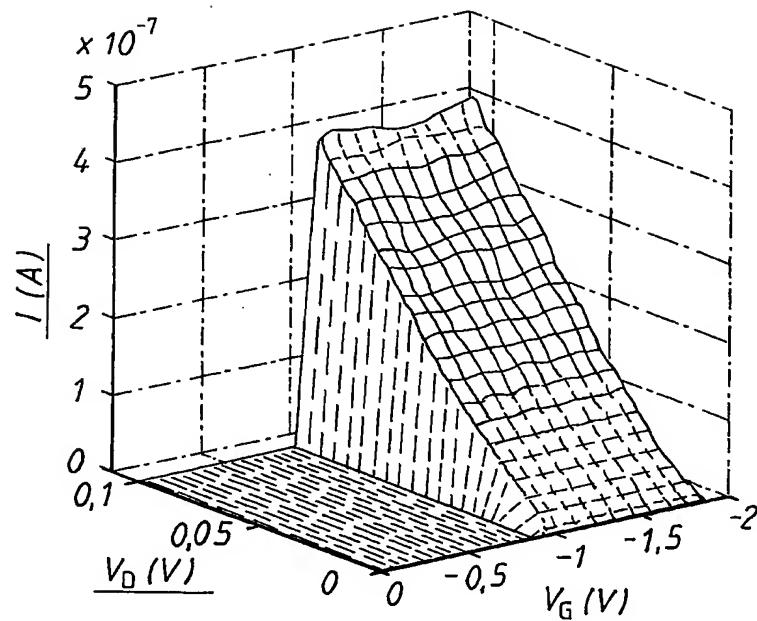
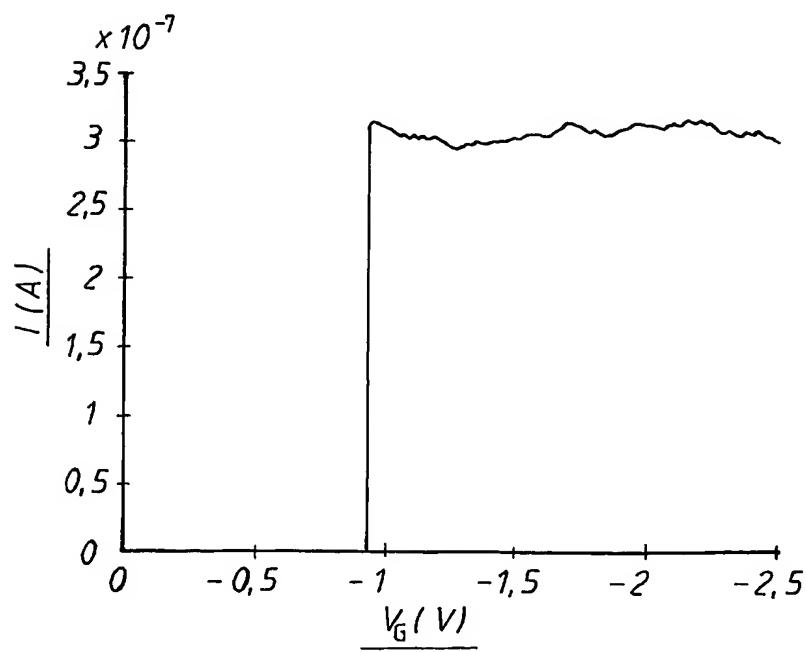
8. A nanotube device according to any of claims 5-7, in which the second means for applying force comprises a second gate electrode, and the second circuit which is closed by the flexing of the nanotube comprises a second drain electrode being located on said third level of the structure.

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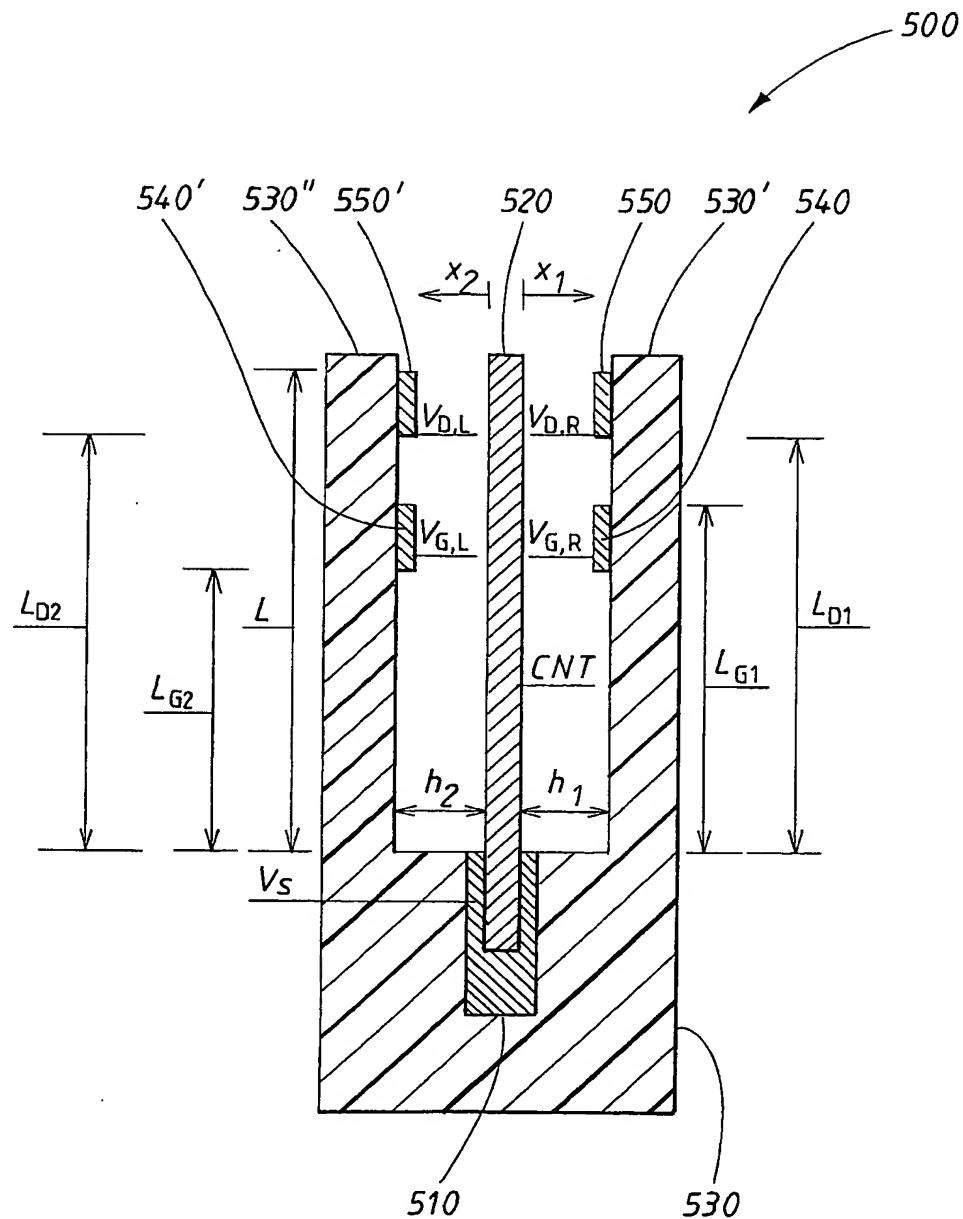
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FIG. 1FIG. 2

2/3

FIG.3FIG.4

3/3

FIG.5

## INTERNATIONAL SEARCH REPORT

International application No. PCT/SE 02/00853
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## A. CLASSIFICATION OF SUBJECT MATTER

**IPC7: B82B 1/00, H01L 29/00**  
 According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

**IPC7: B82B**

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

**SE,DK,FI,NO classes as above**

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**EPO-INTERNAL, WPI DATA, PAJ**

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 10034315 A1 (INFINEON TECHNOLOGIES AG), 31 January 2002 (31.01.02), figure 1B, claims 1-3, abstract  --	1-2
A	WO 0161753 A1 (INFINEON TECHNOLOGIES AG), 23 August 2001 (23.08.01), abstract  -- -----	1-8

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

01/12/02

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 10034315 A1	31/01/02	NONE	
WO 0161753 A1	23/08/01	DE 10006964 A,C	13/09/01